Engine Icing Simulation and Detection

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Overview

• Problem of Engine Power Loss
• Engine Rollback
• Modeling Engine Icing Effects
• Simulation of Engine Rollback
• Icing/Engine Control System Interaction
• Detection of Ice Accretion
• Mitigation of Engine Rollback
• Conclusions
Problem of Engine Power Loss

- More than 200 power loss events reported in last 20 years in High Ice Water Content conditions
  - Temporary or sustained power loss, uncontrollability, engine shutdown
- Many possible causes:
  - Compressor surge
  - Flame-out due to combustor ice ingestion
  - Damage due to ice shedding
  - Sensor Icing
  - Engine Rollback
Engine Rollback

- Associated with ice accretion in compressors

Symptoms:
- Uncommanded thrust reduction
- Decrease in fan shaft speed
- Increase in turbine temperature
- Increasing the throttle does not produce additional thrust

To study rollback, we must be able to realistically simulate it
Modeling of Engine Icing Effects

- C-MAPSS40k engine simulation
  - Commercial 40,000lbf thrust, high-bypass turbofan engine
- Physics-based model
- Realistic engine control system
- Written in MATLAB/Simulink
- Modular design
Modeling of Engine Icing Effects

- LPC Compressor maps with various quantities of ice blockage in the 2\textsuperscript{nd} row stator
- Integrated into C-MAPSS40k
  - Linear interpolation between maps
- Decrease in Surge Line
- Speed Lines shift to the left
Simulation of Engine Rollback

- Impact of Engine Icing
  - Start from nominal conditions and increase the blockage level
  - Move from nominal LPC map to 20% blocked map

- Effect:
  - Drop in EPR -> increase in fuel flow rate and thus increase in $F_{\text{net}}$, $N_f$, $N_c$, $TGT$
  - No Rollback event
Simulation of Engine Rollback

• As blockage increases, eventually a rollback occurs
• Decrease in thrust
• Decrease in fan speed
• Increase in TGT
Engine Control System

- Power Management
  - Responsible for holding current power level (EPR or Nf)
- Protection Logic
  - Responsible for ensuring safe operation
  - Adjusts Fuel Flow to ensure limits are observed
Controller Response To Icing

- Core speed limit prevents fuel flow rate from continuing to increase.
- With limits disabled there is no rollback (but engine is at higher risk of failure due to high core speed).
Detection of Engine Icing

• Typically 5 – 7 sensors present in an engine
• Icing introduces a fault signature that can be detected with these sensors
• Use a Distance Measure (Dm) to determine deviation from expected sensor values
• Operate in conjunction with airframe devices to reduce chance of false-positive

• Developing a technique for full envelope detection
Mitigation of Engine Ice Accretion

• Ideally, completely avoid ice accretion

• If we can detect accretion can the engine controller act to mitigate the impact of the ice blockage?

• Potential mitigation strategies:
  • Operate actuators off-nominally to change operating point to either melt/prevent ice accretion or reduce chance of rollback
    • Close inter-compressor bleed valve
    • Move HPC inlet guide vanes off schedule
    • Use existing airframe integration in novel ways (e.g. customer bleed, power takeoffs)
  • Change shaft speed to cause ice to shed
Future Work

• Complete development of engine icing detection algorithm
• Test various mitigation techniques
  • Work with Turbomachinery and Icing branches at GRC to evaluate results and impact on ice accretion
• Validate models based on data from upcoming (FY13 & 14) engine icing flight tests and rig tests in GRC’s Propulsion Systems Laboratory
Related NASA Publications:


